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TÉTRAUVILLE LIMESTONE OF THE NIOBEC SURFACE CROWN PILLARS: COMPARISON OF STRENGTH AND DEFORMATION PROPERTIES FROM VARIOUS TESTS

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MICROMEDIA

**TÉTRAUVILLE LIMESTONE OF THE NIOBEC SURFACE CROWN PILLARS:
COMPARISON OF STRENGTH AND DEFORMATION PROPERTIES
FROM VARIOUS TESTS**

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ABSTRACT

Limestone from the Niobec Mine surface crown pillars was tested to obtain numerical modeling parameters. Research into the material properties of this sedimentary rock and the applicability of various strength and deformation tests was also carried out.

Brazilian, beam tensile tests and uniaxial compression tests were applied to Tétrauville limestone samples. The results showed that the limestone behaves in a stiff, massive fashion because of the absence of serious bedding weakness. This behaviour was observed in compression and tensile tests. Similar strength values were obtained with various bed orientations.

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key words

surface crown pillars, limestone, beam tensile tests, Brazilian tensile tests, tensile strength, bending modulus of elasticity, uniaxial compression test, uniaxial compressive strength, compression modulus of elasticity, mass strength

**CALCAIRE TÉTRAUVILLE DES PILIERS DE SURFACE DE LA MINE NIOBEC:
COMPARAISON DE SA RÉSISTANCE ET PROPRIÉTÉS DE DÉFORMATION
AVEC DIVERS ESSAIS**

par

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RÉSUMÉ

Des échantillons du calcaire des piliers de surface de la Mine Niobec furent soumis à des essais à fin d'obtenir les paramètres requis d'une modélisation numérique. Des recherches sur les propriétés matériel de cette roche sédimentaire et la validité d'application de divers essais de résistance et de déformation furent également poursuivies.

Des essais de traction brésiliens et de type poutre, de même que des essais en compression uniaxiale furent appliqués à des échantillons de calcaire Tétrauville. Les résultats démontrent que le calcaire se comporte d'une façon rigide et massive à cause de l'absence de faiblesse importante du litage. Ce comportement fut observé dans les essais de traction et compression. Les valeurs de résistance ne changèrent pas d'une orientation de lit à l'autre.

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mots clés

piliers de surface, calcaire, essais de traction de poutre, essais de traction brésilien, résistance en traction, module délasticité en fléchissement, essais de compression uniaxiale, résistance en compression uniaxiale, module d'élasticité en compression, résistance du massif.

INTRODUCTION

The behaviour of rock is often an integral part of engineering projects. In this case, properties susceptible of influencing the stability of the limestone surface crown pillars of the Niobec Mine are examined. This material's orthotropic property characteristics must be taken into account when applying stability evaluation techniques such as numerical modelling, voussoir solutions and elastic/plastic analytical methods. A recent stability evaluation of the Niobec surface crown pillars (1) took the directional characteristics of the limestone into account. From another perspective, testing this limestone marks one of the few times that directional properties of Canadian sedimentary rocks are examined.

NATURE OF THE GEOLOGIC MATERIAL TESTED

The intrusive rock of the Niobec Mine, which contains the niobium concentration, is capped by limestone (2). This sedimentary rock belongs to the Trenton Group of the Ordovician Period, more specifically, to the Tétraville Formation. This identification is possible from:

- 1) regional exposures where it forms the lower contact with the Utica Shale
- 2) its even and regular bedding, uniform composition and dense resistant nature as described by Clark (3).

The limestone is unjointed, massive and shows no tendency to part along bedding. The rock is composed of dense grey carbonate bands, 2 – 5 cm thick, containing several types of fossils, with alternating black shale layers, < 1 cm thick. The density is 2.66g/cm^3 .

Since the limestone is not mineralized, it is left as surface crown pillars over the numerous upper stopes of the mine, figure 1.

TEST PROGRAM

Three types of tests were performed: beam tensile tests, figure 2, Brazilian tensile tests, figure 3, and uniaxial compressive strength tests, figure 4.

The purpose of carrying out beam tests was several fold. It was felt that large beam samples subjected to bending stresses would well represent the action of gravity loads on the surface crown pillars and, for this layered material, would be more representative of than Brazilian tests. It was also recognised that the massive, unjointed nature of the Niobec pillars could be represented by large size beams. Finally, the bending modulus of elasticity

and tensile strength were required for numerical modelling purposes.

The Brazilian test was used for comparison to beam test results. Also, it permitted an appreciation of its suitability for layered rock.

Uniaxial compressive tests were undertaken to obtain further properties for this variety of limestone and to provide the numerical models with required rock parameters. The compressive modulus of elasticity would also be compared to the bending modulus of elasticity. The nature of the stresses imposed on the surface crown pillars indicated that confined compression tests were not required.

Sample preparation methods for these tests are outlined in other reports (4)(5). All the tests were performed with a 1.3 MN Tinius Olsen testing machine.

The beam tests consisted of imposing a load, in a four point fashion figure 2, to rectangular prisms. The central deflection of the bottom chord was measured by an LDVT. The bedding was arranged perpendicular to loading. The beam tensile strength and bending modulus of elasticity were calculated respectively using the following equations (6):

$$\sigma_{T(b)} = \frac{2Pl}{bh^2}$$

$$E_b = \frac{46Pl^3}{27yb h^3}$$

where P =total load applied

l = half the beam length ($2l$) between the supports

b = beam width

h = beam thickness

y = central beam deflection

For the Brazilian tests, the cylindrical discs were oriented in two fashions: with the bedding perpendicular and bedding parallel to the cylindrical disc axis, figure 3. For the latter, the bedding was arranged perpendicular to loading. The Brazilian tensile strength was calculated using the following equation:

$$T_s = \frac{2P}{\pi t d}$$

where t = disc thickness

d = disc diameter

In the compression tests, cylindrical samples with bedding parallel to cylinder axis, and cylindrical samples with bedding perpendicular to cylinder axis were used, figure 4.

Specimen strains were measured with LVDTs and strain gauges. The stress was monitored with a load cell.

The test program parameters sought were:

compression tests $\left\{ \begin{array}{l} \text{peak strength} \\ \text{deformation at peak strength} \\ \text{modulus of elasticity} \\ \text{Poisson's ratio} \end{array} \right.$

tensile tests $\left\{ \begin{array}{l} \text{peak strength} \\ \text{deformation at peak strength (beam)} \\ \text{modulus of elasticity (bending, beam)} \end{array} \right.$

A summary of the test results is found in Tables 1-5

DISCUSSION

When comparing the Brazilian test results for the two different bed orientation, it is evident that tensile strength is only slightly higher for discs with bedding perpendicular to disc axis compared to discs with bedding parallel to disc axis (and perpendicular to load), figure 3. In both cases, the disc failure is limited to cross-bed splitting. When comparing beam tests to Brazilian tests (both with bedding perpendicular to load), it is interesting to note that average strength values are almost identical. The commonly observed size-strength relationship, i.e. a larger volume of rock yielding comparatively lower strength values, is not apparent. This is especially interesting in the sense that beam samples contain several shale layers (weaker material) to the Brazilian disks' one layer (at most). The size-strength relationship, however, is evident in the wider variation from the mean for beams compared to Brazilian discs. This, and the fact that the failure mode in beams was a vertical split (only in a few cases did failure follow shale bands, giving a "stepped" failure surface"), could be explained by the absence of bedding weaknesses in this rock. Thus both tensile test types yield suitable average strength values for this material.

The average compressive strength of the rock is quite similar under both orientations of bedding with respect to load. The deviation from the mean is greater when bedding is parallel to loading. The dominant failure surface in both cases is diagonally planar. Some vertical splitting or blocky failure is present when bedding is parallel to load. This failure mode is accompanied by unusually high modulus of elasticity and Poisson's ratio values. This can be explained by the action of the sample splitting on the diametrical strain gauges used to calculate these two parameters. Though the number of samples tested is small, it can thus be said that material behaviour is influenced to a limited extent by the shale

layers. The ratio of uniaxial to tensile strength is:

$$\frac{\sigma_c}{\sigma_t} = \frac{93}{5.9} = 15.8$$

The bending to compressive (bedding perpendicular to load) modulus of elasticity ratio is:

$$\frac{E_{comp}}{E_{bend}} = \frac{25.9}{0.25} = 103.6$$

Poisson's ratio, for specimens with bedding perpendicular to load, is relatively low. This could be another indication of the stiff, massive nature of this sedimentary rock.

CONCLUSIONS

The beam, Brazilian and uniaxial compression tests applied to the Tétrauville limestone of the Niobec surface crown pillars permit the following observations to be made:

- 1) The limestone behaves in a stiff, massive fashion.
- 2) The orthotropic strength properties are the same.
- 3) The shale bands have a limited influence on directional deformation properties.
- 4) Brazilian and beam tests yield the same average tensile strength.
- 5) The lack of difference between Brazilian and beam test strength results is attributable to the absence of serious bedding weakness. This quasi-isotropic behaviour indicates that Brazilian tests are suitable for determining the tensile strength of this rock type.
- 6) The compressive modulus of elasticity is over 100 times the bending modulus of elasticity.
- 7) The uniaxial compressive strength is over 15 times the tensile strength.

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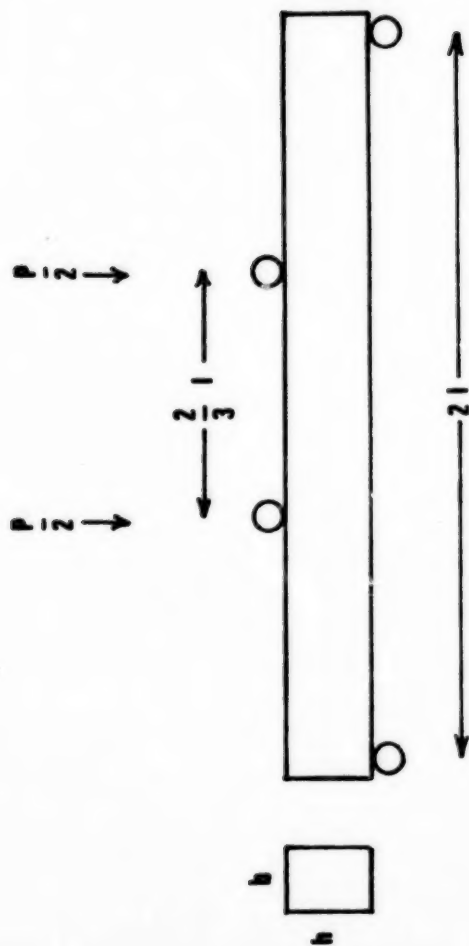


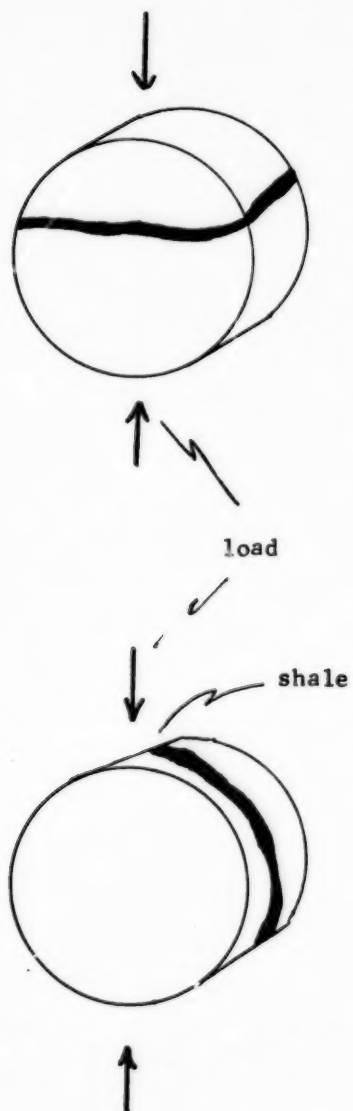
Fig. 2. Beam-type testing apparatus used for tensile tests.

P = Total applied load.

$2l$ = Bottom beam span.

b = Beam width.

h = Beam thickness.



a)

b)

Fig. 3. Arrangement of bedding under Brazilian tensile tests.
a) bedding perpendicular to load, b) bedding parallel to load.

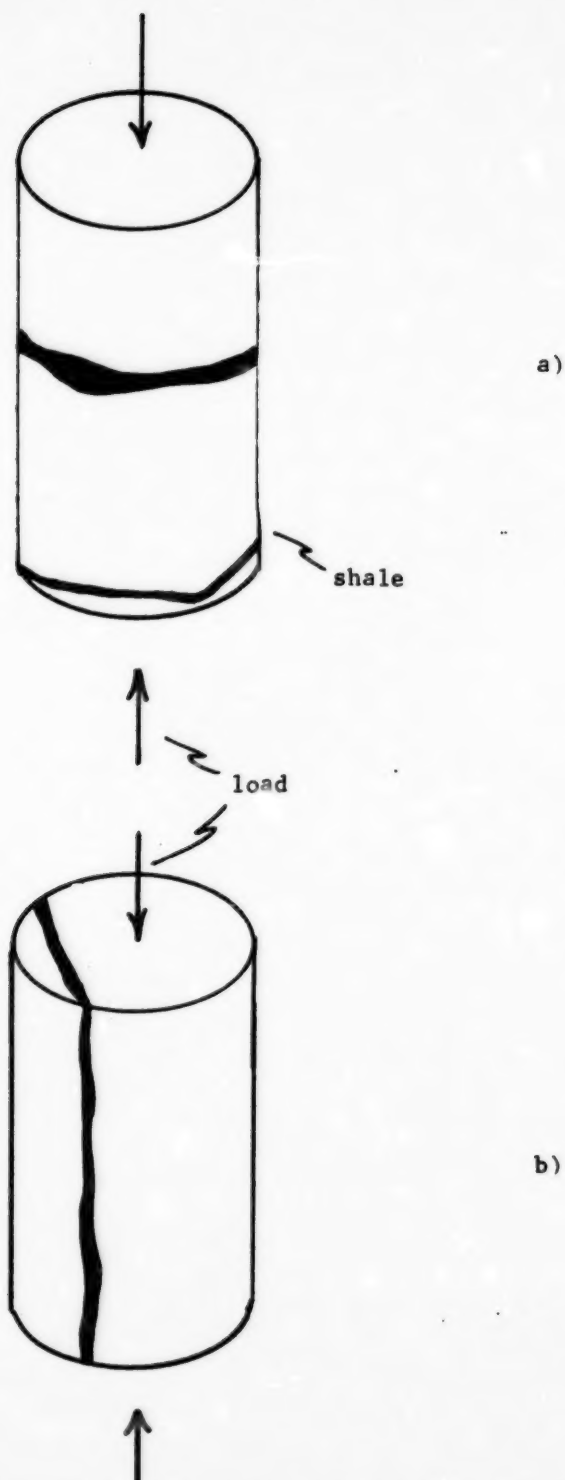


Fig 4. Arrangement of bedding under uniaxial compression tests.
a) bedding perpendicular to load, b) bedding parallel to load.

Table 1

Tensile Properties of the Nibroc Tétrouville Limestone

Beam Bending Tests, Load Normal to Bedding (4)

Sample	Beam Dimensions Height x Breadth x Length (cm)	Tensile Strength (MPa)	Central Deformation (cm)	Modulus of Elasticity (GPa)
4	8.1 x 8.5 x 15.0	6.70	0.26	0.15
7	17.8 x 9.4 x 37.0	5.62	0.42	0.22
10	12.7 x 5.3 x 32.2	2.14	0.17	0.14
15	5.6 x 19.2 x 24.8	10.50	0.33	0.12
16	13.0 x 6.7 x 21.2	5.47	0.57	0.60
17	4.5 x 11.9 x 18.2	3.80	0.24	0.07
18	7.3 x 12.0 x 13.8	8.10	0.39	0.25
19	3.6 x 15.6 x 14.8	5.75	0.36	0.12
20	2.5 x 13.2 x 25.0	3.33	0.34	0.21
22	3.6 x 8.2 x 14.8	9.60	0.35	0.33
		5.87 ± 2.57		$E_b = 0.25 \pm 0.16$

Table 2
NICHEC TETRAVILLE LIMESTONE, BRAZILIAN TENSILE TESTS
BEDDING NORMAL TO DISC AXIS

Sample #	Disc Diameter (cm)	Disc Thickness (cm)	Failure Load (N)	Tensile Strength* (MPa)
A	4.344	2.247	9,230	5.41
B	4.395	2.218	8,800	5.75
C	4.396	2.333	9,320	5.79
D	4.398	2.306	11,530	7.24
E	4.391	2.157	8,620	5.79
F	4.363	2.153	8,820	5.98
G	4.386	2.197	10,180	6.73
H	4.394	2.275	10,540	6.71
I	4.396	2.223	10,880	7.07
J	4.372	2.269	8,350	5.36
K	4.362	2.158	6,850	4.61

$$\sigma_t = 6.04 \pm 0.79 \text{ MPa}$$

$$* T_g = \frac{2 (\text{load})}{\pi (\text{thickness}) (\text{diameter})}$$

Table 3

NIOBIC TERNAUVILLE LIMESTONE, BRAZILIAN TENSILE TESTS

BEDDING PARALLEL TO DISC AXIS, LOAD NORMAL TO BEDDING

Sample #	Disc Diameter (cm)	Disc Thickness (cm)	Failure Load (N)	Tensile Strength* (MPa)
M1	4.389	2.243	10,630	6.87
M2	4.402	2.270	8,180	5.21
M3	4.396	2.265	8,440	5.40
M4	4.395	2.240	8,560	5.54
M5	4.393	2.225	11,180	7.28
M6	4.388	2.209	6,150	4.04
M7	4.398	2.277	10,150	6.45
M8	4.400	2.204	9,860	6.47
M9	4.400	2.255	7,680	4.93
M10	4.400	2.215	5,600	3.66
M11	4.393	2.275	9,740	6.20
				$\sigma_t = 5.64 \pm 1.62$

$$* \sigma_t = \frac{2 (\text{load})}{\pi (\text{thickness}) (\text{diameter})}$$

Table 4

NIOBC TETRAVILLE LIMESTONE, UNIAXIAL COMPRESSION TEST,
BEDDING PERPENDICULAR TO LOADING

Specimen	Length (cm)	Diameter (cm)	L/D	σ_c (MPa)	E (GPa)	ν
A	7.930	4.348	1.82	94.5	26.7	0.15
B	8.206	4.368	1.87	100.8	27.1	0.19
C	8.225	4.369	1.87	78.6	24.4	0.14
D	8.210	4.364	1.87	102.9	32.9	0.13
E	8.221	4.368	1.87	88.4	18.3	0.18
				$\sigma = 93.0 \pm 9.8$	25.9 ± 5.3	0.16 ± 0.03

Table 5

Niobec Trenton Limestone, Uniaxial Compression Test
Bedding Parallel to Loading

Sample #	Length (cm)	Diameter (cm)	L/D	σ_c (MPa)	E* (GPa)	ν	Comments
A1	8.224	4.400	1.87	110.3	77.9/-	1.10	(1) (5)
A2	8.227	4.168	1.97	-	50.7/-	0.16	(2) (4)
A3	8.252	4.173	1.98		46.6	0.22	(2) (4)
A4	8.216	4.174	1.97		40.1/-	0.24	(1) (4)
B1	8.206	4.396	1.87		36.2/-	0.07	(1) (4)
B2	8.220	4.180	1.97		60.1/-	0.25	(2) (3)
B3	8.228	4.172	1.97		44.6/-	0.22	(2) (3)
B4	8.222	4.176	1.97		57.3/-	0.46	(1) (5)
C1	8.212	4.402	1.87		60.3/-	0.20	(1) (3)
C3	8.222	4.178	1.97		46.8/-	0.2	(2) (4)
C4	8.222	4.176	1.97		53.5/-	0.21	(1) (3)
D1	8.226	4.390	1.87		30.2/-	0.20	(1) (4)
E1	8.230	4.388	1.88		61.9/-	2.30	(1) (5)
F1	8.230	4.400	1.87		45.2/-	0.85	(4)
V1	8.226	4.126	2.00	82.1	34.4/30.2	0.03	(2) (4)
V2	8.220	4.100	2.00	110.3	62.4/45.8	0.32	(2) (4)
V3	8.226	4.120	2.00	56.7	20.6/23.9	0.05	(1) (3)
V4	8.228	4.080	2.02	101.9	71.3/46.3	0.29	(2) (1)
V5	8.236	4.098	2.01	106.7	41.8/33.0	0.12	(1) (4)

91.5 $\pm$ 20.0

* Strain gauges/LVDT

- (1) Bedding well developed
- (2) Bedding poorly developed
- (3) Little vertical splitting
- (4) Moderate vertical splitting
- (5) Strong vertical splitting